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ATCHAFALAYA DIVERSION AND ITS EFFECT ON THE MISSISSIPPI RIVER

By Leo M. Odom, M. ASCE

WATERWAYS DIVISION

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PAPERS

ATCHAFALAYA DIVERSION AND ITS EFFECT ON THE MISSISSIPPI RIVER

By Leo M. Odom,[1] M. ASCE

Synopsis

The division of floodwaters from the Mississippi River via the Old and the Atchafalaya rivers in Louisiana is an important factor in the control of the Mississippi River floods below the point of the diversion. Diversion occurs at all stages of the river, and the only control heretofore exercised in the quantity diverted has depended on the resistance of the channel of the Atchafalaya River. These facts create a different problem from that of controlled overbank floodways like those built at Bonnet Carré.

Diversion of water from the Mississippi River to control floods has long been a disputed procedure. One of the most reiterated contentions of its opponents has been that the Mississippi River would adjust its capacity below the diversion to the lesser requirements, as the diversion increased, and that therefore there would be no net gain in total capacity.

A study of the data on discharges versus gage heights reveals that data prior to 1913 cannot be used for comparative purposes without qualification. The data collected since about 1940 must also be evaluated carefully because of changes in procedure in taking measurements.

With these facts in mind a study of the stage-discharge relationship does not indicate any progressive changes in the discharge capacity of the Mississippi River below Old River. The experiments that have been made on movable bed models of bifurcated channels give a clue as to why the normal tendency of an alluvial stream toward adjustment of its capacity to its flow requirements has not been found to operate in this case.

Introduction

The control of the Mississippi River and of its tributaries is the largest civil works project which any government of any country has ever undertaken.

Note.—Written comments are invited for publication; the last discussion should be submitted by August 1, 1950.

[1] Cons. Engr., Baton Rouge, La.

Works of such magnitude are involved that they dwarf any previous or contemporaneous projects of a similar nature to the extent that very few data obtained on other projects are applicable. The part of this huge undertaking assigned to the United States Mississippi River Commission (flood control and improvement of navigation on the Mississippi River below Cape Girardeau, Mo.) is the major and most important part.

Throughout practically the entire length of the Lower Mississippi River, nearly 1,000 miles, the river flows through a bed carved in its own alluvium within a broad flood plain wherein it formerly wandered at will. The funnel-shaped drainage area of the river is 1,245,000 sq miles in extent, but for the lower 600 miles of its length the river receives no major tributary.

Control of the Lower Mississippi River has been under way since 1717 when Le Blond, Sieur de la Tour, built the first levee for the protection of the City of New Orleans (La.). Flood control efforts expanded rapidly from that small beginning; but the problem has only been attacked in a scientific, organized, and adequately financed manner since the passage by the United States Congress of the Flood Control Act of 1928.

Before 1928 the paucity of funds and the lack of a central authority for planning and directing the work restricted activities to levee construction to confine the river to its channel, and to some revetment work to try to stabilize the channel in the most critical bends. Diversions and cutoffs were greatly discussed before 1927; but so much argument could be advanced on either side, because of the lack of dependable information about exactly what their effects would be, that it seemed the best policy to "let well enough alone" and follow the tried policy of building levees bigger and better. The flood of 1927 proved the inadequacy of past measures and brought cutoffs and diversions back into the picture. The act of 1928 provided sufficient funds to undertake their construction.

The most upstream point for logical diversion of water from the Mississippi is into the head of the Atchafalaya Basin, which lies approximately 300 miles by way of the Mississippi River above the Head of Passes. At this point, it is possible to divert tremendous quantities of water through undeveloped swampland to the Gulf of Mexico for the protection of the highly developed section of the valley lying in southern Louisiana below that point. Without this diversion southern Louisiana would be in far greater jeopardy than it was before the completion of levees and cutoffs upstream. While protecting upstream areas, the levees and upstream cutoffs robbed the river of natural storage basins and hastened the flow, thus increasing flood peaks in the lower reaches.

The Atchafalaya Basin (see Fig. 1) is a huge lowland lying west of the Mississippi River in south central Louisiana. It is connected with the Mississippi and Red rivers through the Old River and the Atchafalaya River and empties into the Gulf of Mexico. For thousands of years this basin has served as an outlet for overflow waters from the Mississippi and Red rivers.

The Atchafalaya River, which is leveed on each side for practically its entire length, is a short stream which has its source in Old River and flows as a well-defined stream in the middle of the basin for about half the length of the

basin. It is then lost in a maze of deltaic channels which flow into the lakes at the lower end of the basin. These lakes are connected with the Gulf of Mexico through the Teche Ridge, which otherwise closes the lower end of the basin, by the Lower Atchafalaya River, and by an artificial channel constructed by the Mississippi River Commission called the Wax Lake Outlet.

The Mississippi River Commission and its predecessors in flood control work on the Mississippi have always recognized the importance of the Atchafalaya Basin as a route for diversion. Beginning with the passage of the Flood Control Act of 1928, plans have been prepared and great works have been

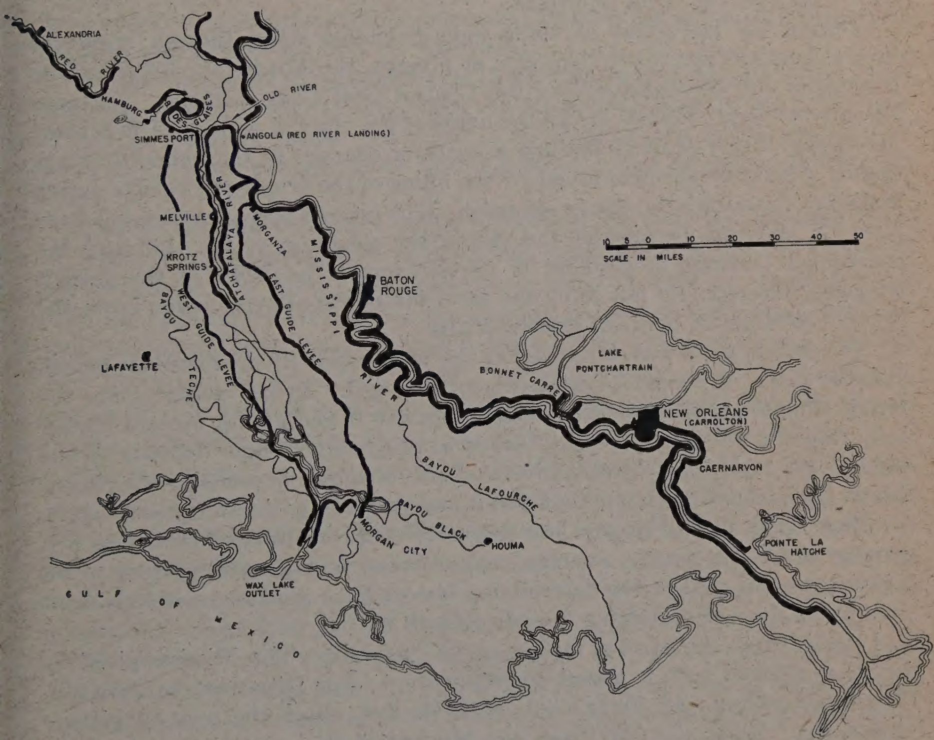

FIG. 1.—ATCHAFALAYA BASIN

constructed with the objectives of utilizing to the fullest practicable extent the diversion possibilities offered by the Atchafalaya Basin and, at the same time, of protecting the fertile lands and prosperous communities lying adjacent to it on each side and in its upper reaches.

The Atchafalaya River originally carried relatively little flow because of the poor development of its channel and the fact that it was blocked near its head by a raft of logs and debris. Improvement of its channel for navigation was begun by the State of Louisiana before 1850. More recently definite steps have been taken by the Mississippi River Commission to increase its discharge capacity so as to alleviate the flood heights on the Mississippi River.

Geology of the Lower Mississippi and Atchafalaya Rivers

The Atchafalaya Basin lies wholly within the deltaic plain of the Mississippi River. The Lower Mississippi River flows through a broad low area from Cape Girardeau to the Gulf of Mexico. This lowland (known as the Mississippi alluvial valley) slopes toward the Gulf and is bordered by abrupt escarpments for almost its entire length. It lies within the Central Gulf Coastal Plain. The deltaic plain of the Mississippi alluvial valley comprises the part of the valley below the head of the Atchafalaya River. It is separated from the flood plain area to the north by the natural levees of Bayou des Glaises and Old River (see Fig. 1) in Louisiana.

During the last stage of world-wide glaciation when the sea level was several hundred feet lower than it is at present, the Mississippi River and its tributaries cut deep channels in the Central Gulf Coastal Plain. The area effected by these channels marks the limits of the alluvial valley. The present Mississippi River evolved through a series of changes in the valley drainage system which were brought about by the filling of the deeply cut valleys during and since the postglacial rise in sea level. The present alluvial valley has been filled by alluvium because of the rise in the elevation of the Gulf and the consequent decrease in gradient of the streams. The filling of the ancient channels, however, did not bring the elevation of the alluvial valley up to the general elevation of the Gulf Coastal Plain.

The deltaic plain was developed as the Mississippi River shifted its mouth and the place of deposit of its sediment changed. In the deltaic plain the recent alluvium reaches depths greater than 350 ft and grades upward irregularly from coarse "gravelliferous" sands to progressively finer deposits of fine sands, silts, and clays. The minimum depth of recent deposits in the Atchafalaya Basin is not much less than 100 ft and the average depth is about 150 ft.

Slope, load, discharge, and the character of the materials forming its bed greatly affect the length, average cross section, and general pattern of an alluvial stream. When the determining factors have remained within reasonable limits for a considerable period, over-all cutting or filling of the stream bed ceases and the stream is said to be "poised." The Mississippi River long ago reached such a poised condition from Cape Girardeau to the Gulf. The local cutting and filling that occur do not affect the over-all picture materially. Below the Old River, the Mississippi River is much more stable than in its upper reaches. The channel is narrower and deeper, high-water slopes are much less, and the bed materials are much more resistant to erosion. The channel is very efficient and it carries its large burden of discharge with very small slopes to the Gulf.

The Atchafalaya River, although offering a much shorter route, has a far smaller cross section, and the resistance of its channel to flow is much greater. However, it flows through erodible material and its average cross section throughout its leveed length has been constantly increasing for many years. This enlargement of the leveed channel has been accompanied by the silting up of the lakes and swamps between the ends of the leveed channel and the lower end of the basin.

History of the Atchafalaya River

The Atchafalaya River was a distributary of the Mississippi River when the region was first visited by European explorers. Geological studies show that it became a distributary long before that time when the lower part of the former Turnbull Bend on the Mississippi River, in Louisiana, caved into an abandoned course of the Red River. This old Red River channel provided a connection from the Mississippi River into the low area that is now called the Atchafalaya Basin. The Atchafalaya River developed slowly below the old channel by forming small distributaries of typical deltaic pattern during each flood and then in later floods choosing one of them to use as its main channel as its delta was pushed out into the basin area.

At the time that the Atchafalaya River was formed, the Red River was following its present course and joined the Mississippi River in the upper limb of the old Turnbull Bend. The head of the Atchafalaya River was about 3 miles farther downstream on the Turnbull Bend. This situation existed until 1831.

In 1831 a cutoff was made in the Mississippi River across Turnbull Bend by Capt. Henry Shreve. As a result of this cutoff the lower limb of the bend, now called the Old River, has become the connection between the Mississippi and the Atchafalaya rivers, and the western part of the old bend forms an extension of the Red River, so that today the Old, the Atchafalaya, and the Red rivers join at a common point. For many years after the cutoff was completed, the upper limb of Turnbull Bend was the principal channel connecting the Red River with the Mississippi River, but it has now silted up.

For many years development of the Atchafalaya River was greatly impeded because the river was blocked by an extensive raft of logs and brush thrown into it by the Mississippi. In 1839 it could be crossed on foot on the raft near its head. The State of Louisiana began work toward the removal of this raft in 1840 so as to create a navigable channel. The reports of the state engineers of Louisiana from 1840 to 1875 contain frequent references to this work.

There was considerable argument about 1847 as to whether the Atchafalaya River should be dammed off. A strong plea for leaving it open, together with the statement that it carried 120,000 cu ft per sec of water during high floods, appeared in 1875.[2]

In 1879 the Mississippi River Commission was created with the duty of preparing plans to improve the Mississippi River channel, to protect its banks, to improve navigation, to prevent destructive floods, and to promote and facilitate commerce. About the same time large levee districts were created in Louisiana and the state engineers turned their attention almost wholly to the task of constructing levee systems along the major streams to protect the alluvial lands from overflow.

The Mississippi River Commission was thus placed in the middle of the argument as to the disposition to be made of the Atchafalaya River as the sole remaining responsible agency in the field. The original policy of the Missis-

[2] *House Document No. 127*, 43d Cong., 2d Session, January 16, 1875.

sippi River Commission with reference to the Atchafalaya River was summarized in its annual report for 1884 as follows:

> "The situation at the mouth of Red River is one which has engaged the attention of the Commission from the beginning of its work ***.
>
> "It is considered that any plan for this work ought to comprehend the prevention of the divergence of the Mississippi River into the Atchafalaya Basin, the closure of any depleting outlet at that point, either existing now or likely to be induced by changes which are reasonably to be anticipated, and the preservation of the navigation of the Red and Atchafalaya rivers."

It was stated in the 1884 report that practically all the flow in the Atchafalaya River came from the Red and the Black rivers and from overflow of the Mississippi River from crevasses above the Old River. The Old River was not enlarging and instead seemed to be filling up.

Efforts were made by the Mississippi River Commission to control the enlargement of the Atchafalaya River and to improve the channel in the Old River for navigation in 1889 and subsequent years in line with the policy adopted in 1884. The channel in the Old River was dredged for many years and finally became self-maintaining. Sill dams were placed across the Atchafalaya River in 1889 near its head. This control section was maintained for about 35 years. During the life of the sill dams the river below the control section enlarged greatly. This enlargement was a result of: (1) Extending the levees southward on both banks of the Atchafalaya River to confine flood flows; (2) improving levees above and below the Old River on the Mississippi River which increased gage heights and, therefore, the energy available for scour; and (3) constructing levees on the south banks of the Old River and of the Bayou des Glaises which prevented overbank flow into the basin and forced the flow down the Atchafalaya River.

The levees along the Atchafalaya River were extended gradually through the years, more or less keeping up with the development of the channel. The progress of the levee extensions is shown in Fig. 2.

The Flood Control Act of 1928, based on the recommendations of the Chief of Engineers contained in the so-called Jadwin Plan, provided for a change in policy of the federal government toward the Atchafalaya River. The Jadwin report stated that it was clearly desirable that the Atchafalaya River be utilized to the extent of its capacity at flood stages to carry waters to the Gulf, and inferred the desirability of the removal of the sills previously constructed near its head. This report also provided for the overbank floodways into the Atchafalaya Basin east and west of the Atchafalaya River.

Study of the Atchafalaya River led the president of the Mississippi River Commission to the conclusion that, without some help, the river would not develop very rapidly, if at all, the relief capacity necessary to secure flood protection below the Old River as proposed by the Jadwin Plan. The swamp section between the end of the river proper and the lakes offered considerable resistance to flow. This part of the basin is largely composed of stiff "backswamp" clays and the current was not capable of scouring an efficient channel in the material. Sedimentation was lessening the flow capacity of this section and causing the gage heights at the lower end of the river levees to increase for equal discharges.

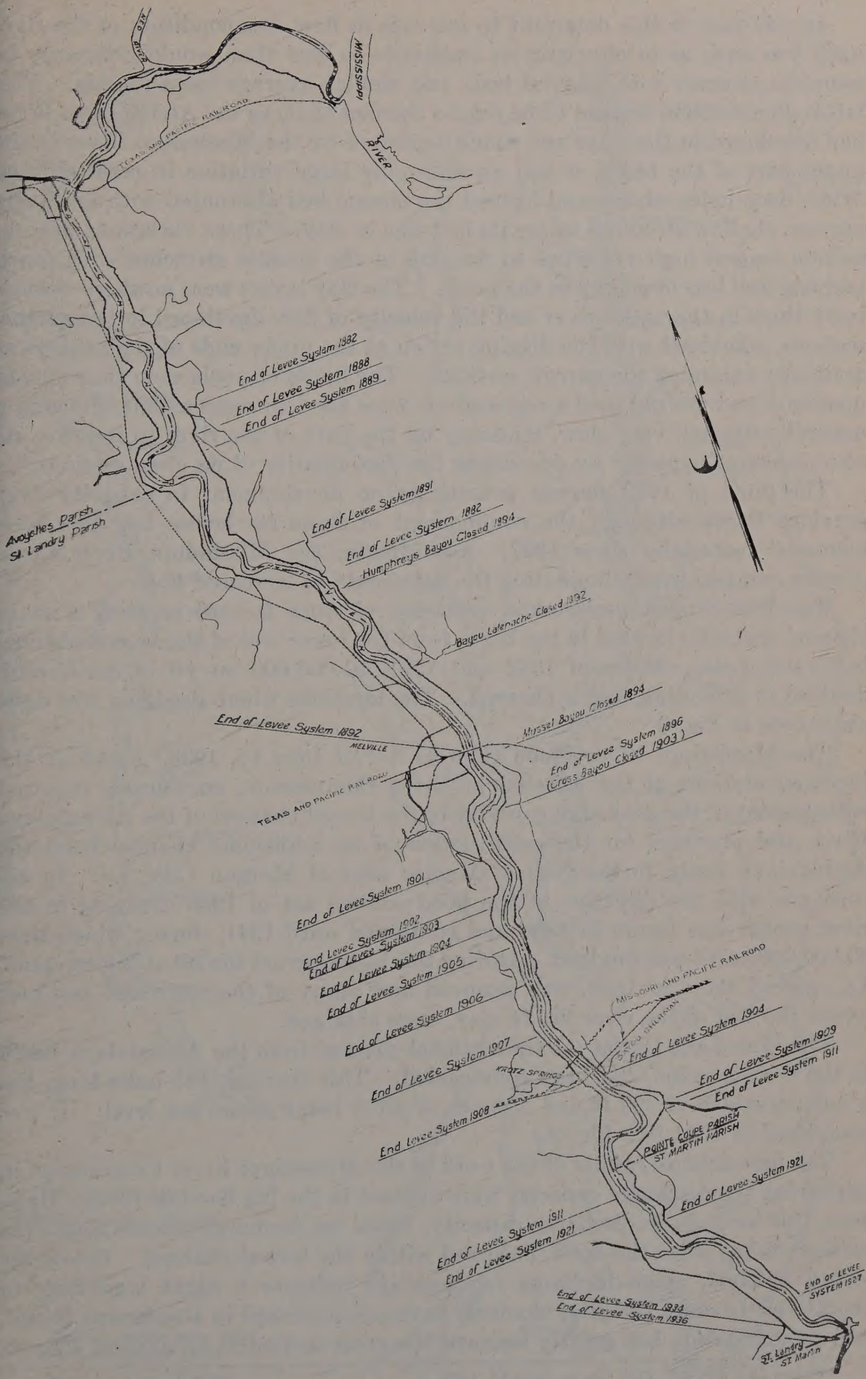

FIG. 2.—PROGRESS OF LEVEE CONSTRUCTION ON THE ATCHAFALAYA RIVER

In addition to this deterrent to increase in flow, the condition of the river itself was such as to offer greater resistance to flow than would ordinarily be found in streams with alluvial beds and similar average cross section. This latter phenomenon seemed to be due to the fact that, as the Atchafalaya River had developed in the clays and sands deposited by the Mississippi River in the upper part of the basin, it had an unusually large variation in cross section. Wide, deep holes where sand formed the stream bed alternated with relatively narrow, shallow stretches where its bed was in clay. These variations in cross section caused high velocities to develop in the smaller stretches with much eddying and loss of energy in the pools. The clay layers were nowhere exceedingly thick in the upper river and the velocity of flow developed in the narrow sections, combined with the digging action at the upper ends of the pools, was gradually enlarging the narrow sections. The limits of pools were thus moved upstream and the old pool cross sections were filled to some extent, showing a natural, although very slow, tendency on the part of the river to improve its own discharge capacity by decreasing the dissimilarity of its cross sections.

The flood of 1932 showed practically no development in capacity over previous floods although the confinement of flows by levees had not been increased materially since 1927. Accordingly, the Mississippi River Commission went to work eliminating the deterrents to increased flow.

The first project undertaken consisted of work toward creating a main channel centrally located in the basin from the lower end of the leveed channel to Grand Lake. Between 1932 and 1941, 91,000,000 cu yd of earth were dredged in providing such a channel. The locations where dredging was done are shown in Fig. 3.

The Mississippi River Flood Control Act of June 15, 1936,[3] based on the recommendations of the Mississippi River Commission, specifically required enlargement of the discharge capacity of the leveed channel of the Atchafalaya River and provided for the construction of an additional channel from the Atchafalaya Basin to the Gulf of Mexico west of Morgan City, La. In accordance with the directive of the flood control act of 1936 dredging in the river proper was begun in 1936 and continued until 1941, during which time 20,000,000 cu yd was dredged. During this latter period the sill at Simmesport, La., placed there in 1889, was removed and many of the restricted sections, where the bed of the river lies in clay, were enlarged.

The Wax Lake Outlet (as the artificial channel from the Atchafalaya Basin to the Gulf is called) has been constructed. This channel, 115 miles long, has a bottom width of 300 ft and a depth of 45 ft below mean sea level. It was completed in 1941 (see Fig. 3.)

The first definite results of the work of the Mississippi River Commission in improving the discharge capacity were evident in the big flood of 1945. However, this increase in discharge capacity, based on discharge records and cross sections taken after the flood, occurred within the leveed channel. Below the leveed channel, stage-discharge relationships indicate a slight worsening of conditions, because the pilot channels have not increased in size as was hoped, and sedimentation has greatly lessened the cross section at equivalent stages.

[3] *Public Law No. 678*, 74th Cong., June 15, 1936.

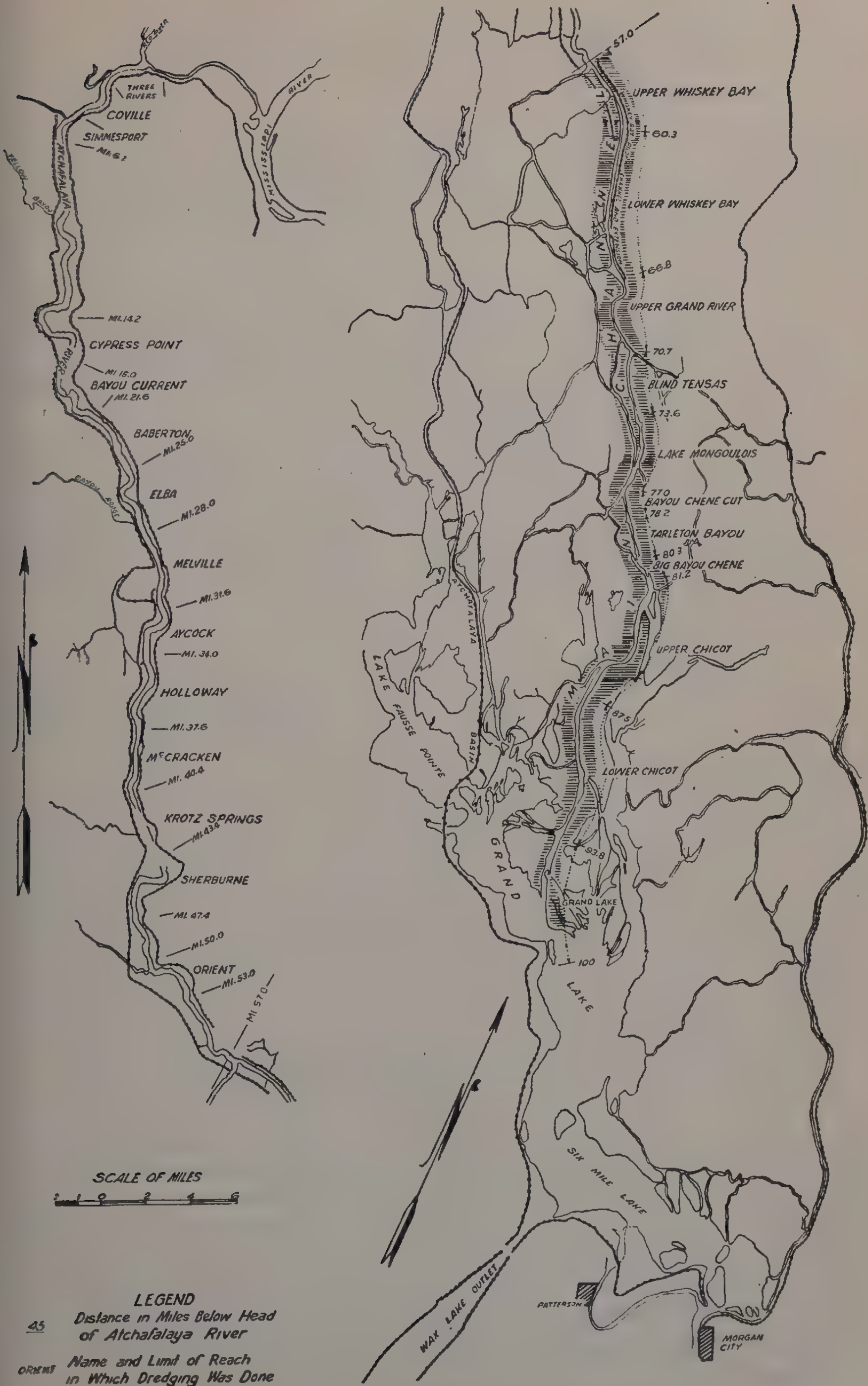

FIG. 3.—MAIN CHANNEL DREDGING, ATCHAFALAYA BASIN

Effect of Diversion Into the Atchafalaya River on the Capacity of the Mississippi River Below the Old River

The ultimate effect, on an alluvial stream, of the diversion of part of its waters was the subject of acrimonious debate among engineers for many years and resulted in the "levees only" policy of the Mississippi River Commission which prevailed until the 1927 flood proved that adequate protection of the lower river could never be accomplished by adhering firmly to such a policy.

The position of the antidiversionists was well summarized by J. A. Ockerson,[4] M. ASCE, as follows:

> "The controversy as to the efficacy of outlets or, in other words, the diversion of a portion of a flooded stream to secondary channels, for the purpose of reducing flood heights, began in Europe several centuries ago and was transferred to this country during the early days of levee building in Louisiana over a hundred years ago.
>
> "In Europe, outlets for flood relief as applied to alluvial streams flowing in beds of their own formation, were long since rejected through the actual experience of eminent hydraulic engineers.
>
> "No new facts have been developed which controvert the fundamental law of hydraulics that the reduction by means of secondary channels of the volume of an alluvial stream flowing in a bed of its own formation will reduce the capacity of the main stream, which will ultimately result in an increased flood height at and near the point of diversion and throughout the channel below same."

The fundamental law to which Mr. Ockerson referred was that proposed by Domenico Guglielmini in the latter part of the seventeenth century. That law formed the basis for most of the reasoning which led to the decision of the Mississippi River Commission to recommend against diversions for flood control before the 1927 flood.

The Guglielmini theorem has been generally interpreted as a proposition that an alluvial stream automatically adjusts its bed to correspond to its flow requirements. It was evolved at the time in history when the dependence on pure logic as a tool for reaching conclusions was at its height, but sufficient data to prove or disprove such conclusions were often lacking. How a stream operates to adjust its bed to its flow requirements; what particular flow (in the case of a stream of widely fluctuating discharge) would be selected by the stream as its goal; and how long it would take the stream to make adjustments to changes—these factors were not discussed by Guglielmini; nor have they been adequately discussed by later proponents of the theorem.

Mr. Ockerson's statement, that no new facts had been developed to controvert the theorem, is as true today as in 1915—provided, however, that the theorem is recognized as a tendency rather than as an incontrovertible law and that the tendency of a stream to adjust its cross section to its flow requirements by scour or deposition is frequently combated quite effectively by other phenomena of stream flow.

The main reason why the action of an alluvial river is so little understood has been expressed succinctly by D. O. Elliott,[5] M. ASCE, as follows:

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[4] *Professional Memoirs*, by J. A. Ockerson, Corps of Engrs., U. S. Army, Engr. School, Washington Barracks, D. C., September–October, 1915.

[5] "The Improvement of the Lower Mississippi River for Flood Control and Navigation," by D. O. Elliott, U. S. Waterways Experiment Station, Vicksburg, Miss., 1932.

> "The power of running water to entrain and transport solids of various degrees of comminution and density, remains, after a century and a quarter of investigation a phenomenon for which no generally recognized laws have been deduced."

It can be stated indisputably that, in spite of an additional 16 years of much more intensive investigation, generally recognized laws are yet to be deduced.

To dispute or to defend, scientifically, any theory about the action of an alluvial river, the basic requirement would be the establishment of general laws, incontestably correct, covering the basic actions of a stream in picking up and handling solids. Therefore, it would not seem to be worthwhile to waste much time disputing as to whether such theories should be accepted. An engineer, being practical, would undoubtedly require some dependable information about angels before he would argue about how many of them could stand on the point of a pin.

In permitting and encouraging the diversion of water from the Mississippi River into the Atchafalaya River, the Mississippi River Commission was not acting on theory but on necessity, since it appeared to be impossible for the main river to be confined sufficiently so that it would carry large floods to the sea unaided. An analysis of the available data has been made (without reference to general laws or theories) to determine whether the Mississippi River has lost capacity as the Atchafalaya River has gained capacity, as the "Guglielminists" have forecast for generations. If the main river did lose capacity as the diversion increased, or if such an occurrence seems probable, the navigation channel in the Mississippi River will soon be a thing of the past and the inhabitants of the valley below the Old River are in greater jeopardy from floods than they ever were.

The factors which are known to influence the capacity of a stream are its cross-sectional area, its length, the shape of its cross section, the roughness of the channel, the variability of its cross section, and its sinuosity. Changes in capacity are influenced by the character of the bed and banks of the stream and its tributaries, the variation in flow, and the existence of diversionary channels. Adequate data for a comparative study through the years of each of these elements are not available. Such data as have been collected must be scrutinized very carefully to insure that a true comparison of the various features is secured. For instance, in regard to cross sections, ranges selected as perpendicular to the river during one year are frequently not so in succeeding years and if not changed will invariably indicate increases which have not occurred.

In taking cross sections of a large stream the technique of the leadsman and the weight of the lead introduce possibilities of variation in results, which can obviate the value of the most scientific line of reasoning. Modern practice in determining depths with a supersonic echo sounding device undoubtedly provides the truest picture of the cross section that has ever been available; but, when conclusions are to be drawn from comparisons with data collected by the older practices, it is quite possible that these comparisons will lead to somewhat erroneous results.

The measurement of flow in rivers has also been subject to great improvements in technique and equipment, and again the personal equation may result in considerable error. All the older measurements were made with floats. These are now known to be very inaccurate. Metered measurements, particularly during high stages, are subject to errors and are greatly affected by the weight used with the meter and by the number of readings taken in a cross section where practice has been known to vary considerably through the years. It would appear, therefore, that too much credence cannot be given to small apparent variations and that great refinement in the comparison of available data would be useless.

Analysis of Stage and Discharge Measurements

Various studies have been made in the past in an attempt to determine whether the Mississippi River has lost capacity because of the Atchafalaya diversion. Of these, the method of analysis used by E. F. Salisbury,[6] M. ASCE, is apparently the least troublesome method and should give nearly correct answers. Mr. Salisbury assumed that the gage height which will be reached at a selected gaging station, when passing a given discharge, is a measure of the resistance to flow of the channel from that gaging station to the sea. The gage heights when this discharge was reached, compared over a number of years, should provide the answer as to whether the capacity of the channel is changing.

E. W. Lane,[7] M. ASCE, in an excellent discussion of Mr. Salisbury's paper, presented several graphs showing the stages at Red River Landing at several selected discharges for the years from 1882 to 1930, inclusive, and on each of these graphs of stages he drew a mean line which he considered would indicate the trend of the capacity of the river.

The stage graphs presented by Mr. Lane for four discharges—800,000 cu ft per sec, 900,000 cu ft per sec, 1,000,000 cu ft per sec, and 1,100,000 cu ft per sec—were prepared from available current meter measurements between 1,150,000 cu ft per sec and 750,000 cu ft per sec. The stages for each discharge within 50,000 cu ft per sec of the even 100,000 cu ft per sec were adjusted to the nearest even 100,000 cu ft per sec by using the discharge increment corresponding to that discharge. All measurements that might have been affected by crevasses were eliminated, except those of 1882. The adjusted stages were plotted against their respective years for each of the four discharges. The mean of the adjusted stages for each discharge in each year was plotted. Two other sets of elevations were also plotted showing, respectively, the lowest adjusted stage and the highest adjusted stage in respective years. Above each set of points the number of observations on which the points were based was given. For each discharge Mr. Lane drew a straight line on the graph to show the general trend through the years.

Using Mr. Lane's method, the writer has extended those graphs of stages plotted against selected discharges to 1945, as shown in Fig. 4. The trend

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[6] "Influence of Diversion on the Mississippi and Atchafalaya Rivers," by E. F. Salisbury, *Transactions* ASCE, Vol. 102, 1937, p. 75.

[7] *Ibid.*, p. 109.

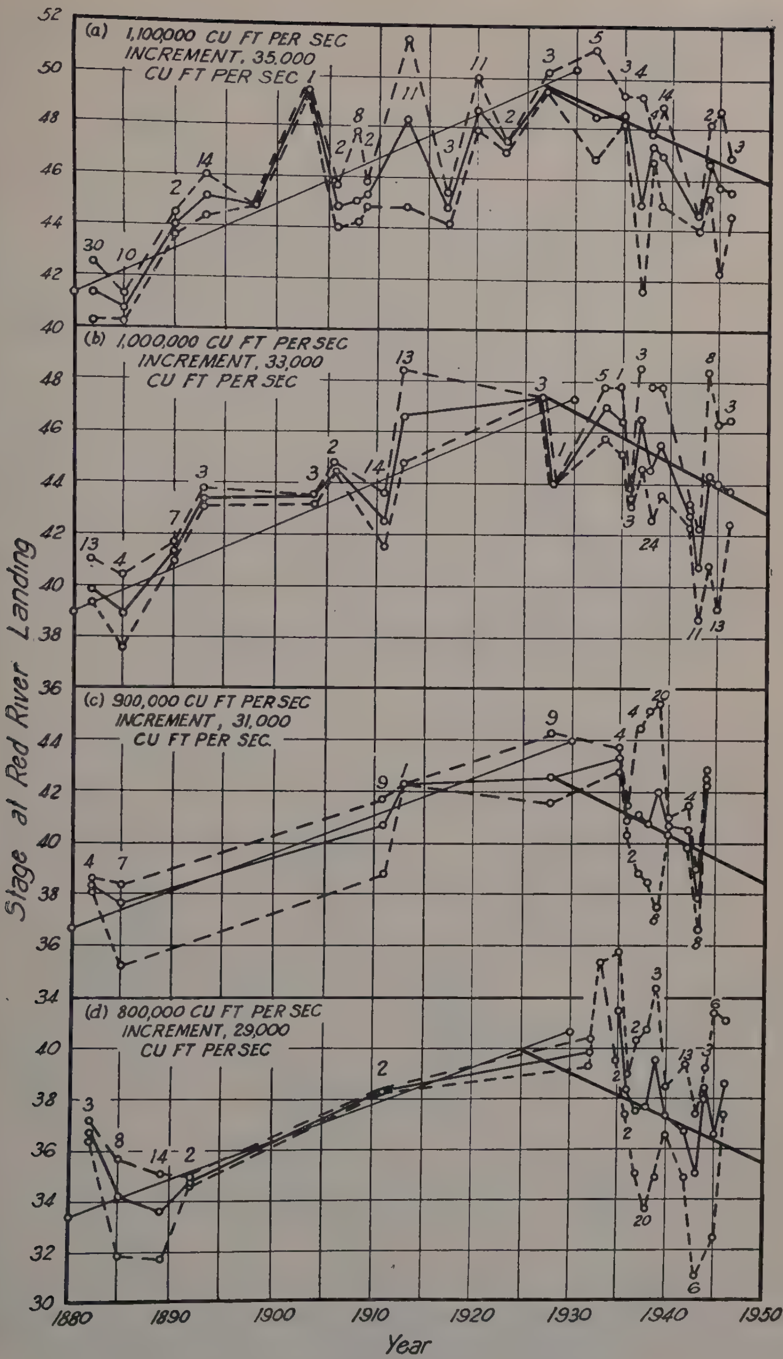


FIG. 4.—STAGE OBSERVATIONS AT RED RIVER LANDING

toward loss of capacity below Red River Landing prior to 1927, as indicated by Mr. Lane's graph of stage-discharge relationships, reversed itself about that time and the capacity of the Lower Mississippi River has been steadily im-

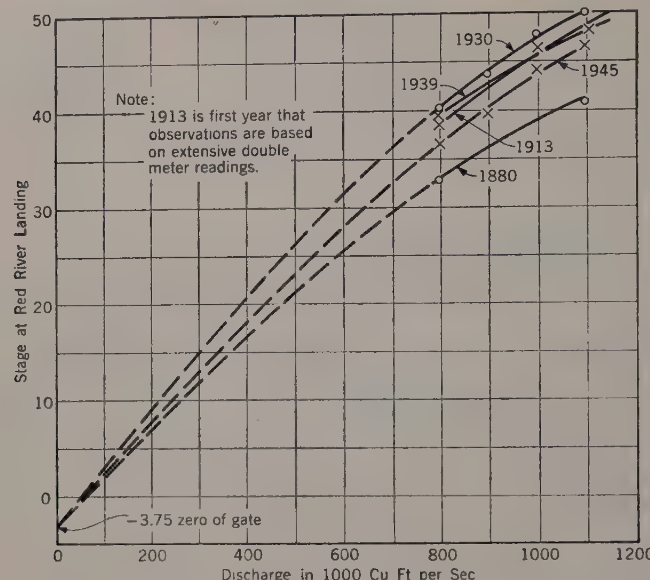


Fig. 5

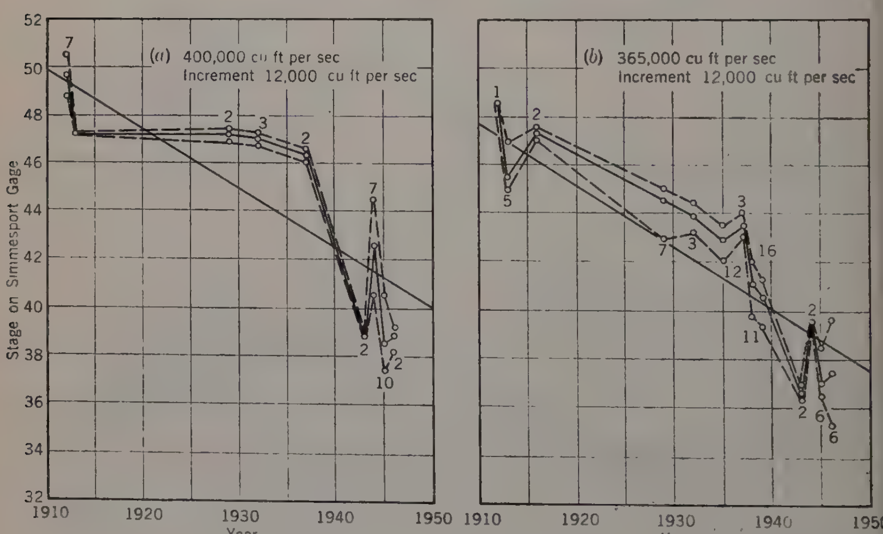


Fig. 6.—Stage Observa

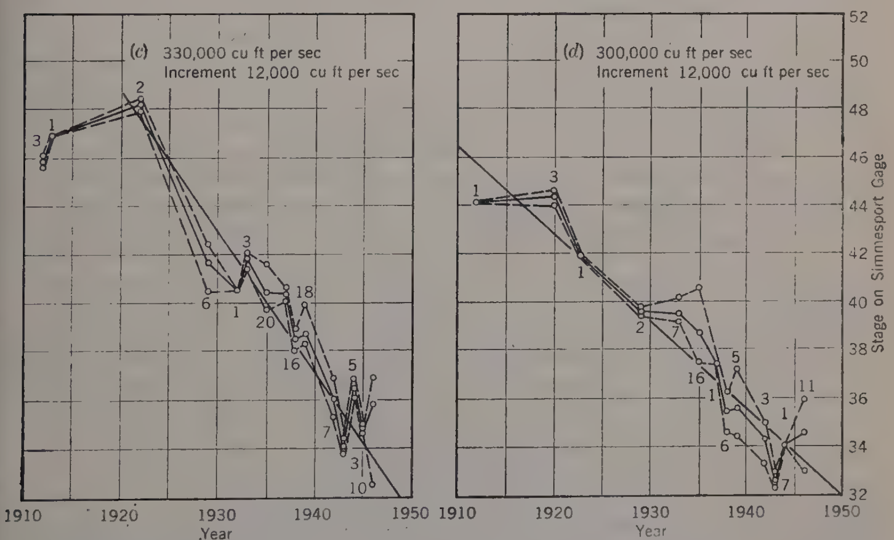
proving. Mr. Lane also plotted rating curves for the Red River Landing gage from the mean stage lines for the years, 1880 and 1930. These rating curves indicated a loss in capacity of 250,000 cu ft per sec at a stage of 40 ft.

The writer has added to Mr. Lane's curves rating curves plotted from the mean lines in Fig. 4 for 1913, 1939, and 1945, as shown in Fig. 5. The year 1913 is the earliest in which a sufficiently wide range of double-metered measurements is available to justify comparison with later years. The years 1939 and 1945 were selected because of the large number of measurements available within the range of the selected discharges.

A gain of 100,000 cu ft in discharge capacity at a stage of 40 ft is indicated by the rating curves between 1930 and 1945. The 1913 and 1939 curves lie quite close together, about midway between the 1930 and 1945 curves. These curves would indicate that the capacity decreased from 1913 to 1930 and then gradually increased to 1945.

Graphs of the stages at Simmesport on the Atchafalaya River for the years 1913 to 1945, inclusive, for discharges of 300,000 cu ft per sec, 330,000 cu ft per sec, 365,000 cu ft per sec, and 400,000 cu ft per sec were plotted from data prepared in accordance with Mr. Lane's method. Equivalent discharges at much lower gage readings show conclusively the great increase in the capacity of the Atchafalaya River during that period. These graphs are shown in Fig. 6.

Reference to Fig. 6(*a*) will show that gage heights for a flow of 400,000 cu ft per sec have decreased 8 ft between 1910 and 1945. Figs. 6(*b*), 6(*c*), and 6(*d*), show the decrease in stage for the respective discharges analyzed. The mean stage lowering at the four discharges is 0.37 ft per yr. In 1937, 471,000 cu ft per sec passed Simmesport on the Atchafalaya River at a gage height of 55.0 ft above mean Gulf level (MGL). In 1945 three discharge measurements



TIONS AT SIMMESPORT GAGE

(April 27, 28, and 30) at a stage of 57.2 ft MGL were obtained. These were 637,000 cu ft per sec, 661,000 cu ft per sec, and 645,000 cu ft per sec. If the peak flow in 1945 is considered to have been 640,000 cu ft per sec, an increase

in flow of 36% with a stage increase of only 4% occurred between 1937 and 1945. In 1945 the peak discharge of the Atchafalaya River at Simmesport was 43.7% of that of the Mississippi River at Red River Landing on the same date, as compared to 32.2% in 1937. The measured discharges at Red River Landing on the dates of the peaks at Simmesport in 1937 and 1945 were practically equivalent.

Most of the data collected before 1913 are believed to be useless for comparison with later data. However, the period from 1913 to 1945, inclusive, provides a range of 33 years which should be long enough to determine if a trend exists. The only possible conclusion from the data is that the Mississippi River has not lost capacity as the Atchafalaya enlarged; actually it has more capacity today than it had in 1913, in spite of the fact that the Atchafalaya River is taking a much greater proportion of flood flows. Because this conclusion is exactly opposite to that reached by most previous students of the subject, several of these prior studies have been analyzed, and reasons sought to discover why this apparent increase in capacity has occurred despite the previous findings.

Variation in Annual Flow Reaching the Mouth of the Old River

A factor to be considered in the study of the effect of the diversion into the Atchafalaya River concerns the question of whether the annual runoff reaching the Mississippi during the period of flow has changed materially. If

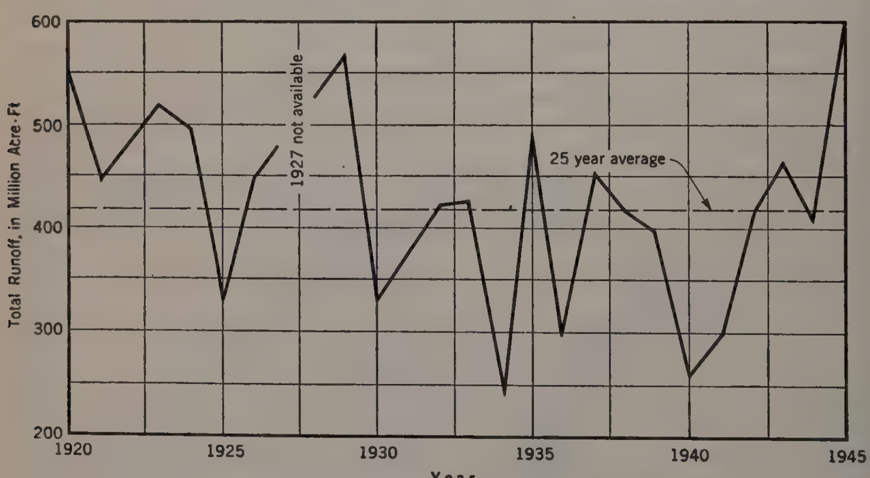


Fig. 7.—Mississippi Hydrograph at Vicksburg, Miss., 1920–1945

sufficient additional flow had become available to take care of the increase in diversion, the average flow in the Mississippi River past Red River Landing might remain the same as in the past. The amount and concentration of runoff are dependent on meteorological conditions. Floods occur as a result of general, intensive rains over the basins of the various tributaries, spaced in time so as to cause the flood runoff of each tributary to reach the main stem as

its flood discharge is passing that point. Man-made regulatory works on the main stem and tributaries are known to affect the timing of the concentration of runoff only slightly as far as the lower river is concerned. Fig. 7 shows the hydrograph of the Mississippi River at Vicksburg, Miss., from 1920 to 1946. The ordinate is the runoff in millions of acre-feet. (Flow entering the Mississippi River between Vicksburg and the Old River is only a small fraction of the total flow, and has been disregarded.) An inspection of Fig. 7 shows that the Mississippi River Basin experiences wet years and dry years, but the annual average volume of flow reaching the mouth of the Old River has changed very slightly.

Accuracy of Flow Measurements

The period covered by this study has seen a gradual continuing effort made by the Corps of Engineers, United States Department of the Army, and the United States Geological Survey to improve stream measuring procedures. At first, depths were measured with chains and velocities were obtained by surface floats. Depths are now measured by Fathometers; and velocities are measured by Price current meters, at one or more depths.

The writer does not question that the latest methods are the best, but he does question the unadjusted comparison of data obtained by early methods with data obtained by the latest methods. Some of the apparent decrease and the subsequent increase in discharge capacity at Red River Landing may be attributable to the comparison of data obtained by different techniques.

TABLE 1.—Stage-Discharge Relationships at Baton Rouge, La.

(Units Are in Cubic Feet per Second)

Stage (ft)	1939	1945	Change
32	895,000	975,000	+80,000
34	950,000	1,043,000	+92,000
36	1,012,000	1,106,000	+96,000
38	1,077,000	1,171,000	+94,000
40	1,140,000	1,236,000	+96,000

To try to answer this question, a gaging station in a relatively stable regimen, with minute changes below it, was sought. The discharge range at Baton Rouge, La., was thought to be best for the following reasons:[8]

> "Bed of sand clay, and silt. High-water control is affected by levee on right bank, and by high ground and levee on left bank. Stage and discharge are affected by diversion into Atchafalaya River through Lower Old River, and during low stages by tides of the Gulf of Mexico. Stage-discharge relation is fairly consistent for high and medium stages, but is affected by tides during low stages."

A comparison of stage-discharge relationships through the years at Baton Rouge should reflect any changes in results stemming from changes in stream measuring procedures. Using only meter measurements, the 1939 and 1945 stage-discharge graphs were plotted. A comparison of these years is given in Table 1. An apparent increase in discharge capacity is shown at each stage ranging from 8.9% at 32 ft to 8.4% at 40 ft.

[8] "Stages and Discharges, Mississippi River and Its Outlets and Tributaries, 1946," Mississippi River Comm., Vicksburg, Miss., p. 51.

Inasmuch as the Mississippi River regimen downstream from Baton Rouge is considered by nearly everyone to be relatively stable, it must be concluded that most of the apparent increase in discharge capacity of the river at that point is due to the "improvements" in gaging procedures which are known to have been instituted since 1940.

Dredging Below the Mouth of the Old River

It will be noticed that Fig. 4 shows the greatest improvement in channel capacity at Red River Landing after about 1938. Prior to that time,[9] a sand bar having an elevation of + 10 MGL extended from mile 299.7 to mile 298.8 above Head of Passes (AHP). Also, at Smithland, La., 3 miles below the mouth of the Old River opposite the Old Raccourci Cutoff, a towhead with its split channel had been formed. The narrow chute on the west side had depths to − 23 MGL, but the wide channel on the east side of Miles Bar had depths to only 0 MGL, or about 8 ft below mean low water. Below the towhead, at mile 296.5, there was a deep hole with an elevation of − 70 MGL. The sand bar and split channels constituted a restriction to flow, the former being a product of the action of the latter. Actually, the sand bar could be considered an extension of Miles Bar, so that the split channel existed from mile 299.7 to mile 296.7, not from mile 298.1 to mile 296.7.

To eliminate these restrictions to flow, Gen. H. B. Ferguson, M. ASCE, in 1938, directed that "corrective dredging" be undertaken in the reach opposite Smithland. The following is quoted from a report on that subject:[10]

> "The objective of the work at this location is to obliterate the split channel at the head of the old cut-off, improving the east side channel and to extend deep water upstream.
>
> "Excepting a few minor shoals, deep water extends upstream a distance of 314 miles from the river's mouth to Mile 296.5. From Mile 296.5 on upstream to Mile 301 deep water occurs intermittently with minor shoals between. To correct these conditions the deep water at Mile 300.5 down to deep water at Mile 296.5 was connected in 1938 by a series of cuts to a depth of approximately minus 25 feet M.G.L. These cuts were made in several separate operations. A careful running observation was conducted and the plan of dredging work was modified from time to time to conform to whatever natural trends the river seemed to be taking.
>
> "From Mile 300.5 down to Mile 298.5, the spoil was so disposed as to effectively exchange excessive width for depth, the majority of the spoil being placed against the east bank. Throughout the work in this vicinity many pockets of gravel were encountered and much debris was found embedded in old deposits. From Mile 298.5 down to Mile 296.5, the cuts followed down the center of the channel to the east of a middle ground. The material encountered here was much lighter than that found above, consisting principally of fine sand. Some of this material was deposited on the head of the middle ground in order to influence further deposits by the river to raise the elevation of this gently sloping sand bar which formed the east bank in this vicinity, so placing the spoil as to provide more definite banks. A cut was made along the right bank between Mile 296.5 to 296.0 to remove the extremely tough clay, which borings had disclosed

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[9] "Mississippi River Hydrographic Surveys," Mississippi River Comm., Vicksburg, Miss., October, 1937.

[10] "The History of the Improvement of the Lower Mississippi, 1932–1939," Mississippi River Comm., Vicksburg, Miss.

to exist in this vicinity. Partial removal of this point immediately provided some betterment in alignment of the channel coming down the east side of the middle ground and into the deep water at Mile 296.5."

(To conform to present-day river mileage, the mileage in the excerpt has been changed from miles below Cairo, Ill. (BC), to miles above Head of Passes—thus, mile 300 AHP = mile 772.5 BC.)

Table 2 is a comparison of depths in the Smithland reach, between miles

TABLE 2.—COMPARISON OF CHANNEL DEPTHS IN THE MISSISSIPPI RIVER BELOW RED RIVER LANDING (MEAN GULF LEVEL DATUM)

Mile (AHP)	October, 1937	September, 1942	September, 1944	September, 1945
300.5	−12	−15	−50	−40[a]
299.5	+10[b]	−18[c]	−25[d]	−23[e]
298.5	− 3[f]	−14[g]	−23	−20[h]
297.5	−23[i]	−20[j]	−12[k]	−29[l]
296.5	−70	−70	−40	−40

[a] At mile 300. [b] Sand bar extending from mile 299.7 to mile 298.8. [c] Sand bar eliminated. [d] Channel shifted from center to west side. [e] El. −23 on west side; slight bar in center to El. +3. [f] Split channel from mile 299.7 to mile 296.7. [g] Upper end of west channel closed to El. +13. [h] El. −5 at center; El. −20 on west side. [i] El. −23 on the west side; El. −0 on the east side. [j] El. −20 on the west side; El. −27 on the east side. [k] Chute closed. [l] West chute open between mile 297.3 and mile 296.7.

300.5 and 296.5 AHP, for four hydrographic surveys, beginning in 1937 and ending in 1945. The "corrective dredging" was effective, depths throughout the reach being increased and the chute on the west side of Miles Bar closing up. The closing of the chute concentrated the river energy into one channel—the east—with subsequent improvement of that channel. Whereas, prior to 1938, the Smithland reach was a flow restriction, it no longer can be considered such.

DIVERSION OF SEDIMENT AT A CHANNEL BIFURCATION

Several important laboratory studies of the diversion of sediment at a channel bifurcation have been made. Inasmuch as a complete analysis of existing data concerning the diversion of sediment would not be within the scope of this paper, only pertinent references will be cited and general conclusions drawn from them.

The problem was first studied in Europe by H. Thoma of Munich, Germany, at the request of a power company. That company, situated on the Middle Isar River, in Germany, was troubled by sedimentation at the intakes of its power plants. Later, Th. Rehbock and H. Bulle studied the problem at Karlsruhe, Germany. The early investigators (1923) used rectangular flumes, the size of the main channel and bifurcating channel being identical (0.66 ft wide). The ratios of bed load diverted for different bifurcation angles were as given in Table 3. These experiments demonstrated that for an equal division of flow the branching channel diverts the major part of the bed load. In summarizing his work Mr. Bulle noted:

(*a*) Just inside the branching channel and opposite the point of diversion, a roller or eddy was formed. This roller varied in intensity with the angle of

diversion, and with the form of the diversion point. It operated to contract the section of the branching channel, and so to increase slopes at its mouth.

(*b*) Relative to the percentage of water carried by the side flumes the percentage of "geschiebe" (bed-load material) deposited was always very large.

TABLE 3.—PERCENTAGES OF TOTAL BED LOAD DIVERTED FOR DIFFERENT BIFURCATION ANGLES (50% OF THE TOTAL WATER WAS DIVERTED IN EACH CASE)

Magnitude	Angle of Bifurcation (Degrees)				
	30	60	90	120	150
Percentage of total bed load diverted.....	97.3	96.2	90.5	87.5	92.0

(*c*) A rounded corner at the convex side of the side channel entrance (tested only for angles of 30°, 60°, and 90°) tended to decrease the side channel contraction produced by the roller, and also decreased the transverse slope at the point of diversion. More water but less "geschiebe" was carried into the side channel as the result of the rounded corner.

In 1932 K. D. Nichols and C. D. Curran, Assoc. M. ASCE, began similar studies at the Waterways Experiment Station in Vicksburg. Gerard H. Matthes, Hon. M. ASCE, writes of the Vicksburg experiments:[11]

> "Similar experiments * * *, with flumes of various types, do not confirm the high ratios above quoted [see Table 3], but indicate that the branch-channel carries, in proportion to its discharge capacity, more bed-load than the straight channel does below the point of diversion. * * * In one of the flume experiments made * * * it required 70 hours of continuous operation to bring about a condition of equilibrium. During the first 14 hours the bulk of the bed-load materials entering the branch-channel dropped and built up bars. This was followed by a period of bed-load travel in which dunes and loose materials progressed with regularity. The stabilized condition showed the branch-channel to discharge about 37 per cent of the total flow, and about 66 per cent of the total bed-load. It was found, furthermore, that the bed-load movement, although consisting of these two distinct forms, always totaled the same. In this instance the branch-channel did not fill with sand, but maintained its discharge capacity while at the same time carrying more sand in proportion to its discharge than the main river-channel."

The discrepancy between the German findings and those of the Waterways Experiment Station may be explained in this manner: In the earlier experiments by Messrs. Rehbock and Bulle, rectangular sections of equal area were employed in the two flumes, and the discharges in the two flumes were likewise maintained. Messrs. Curran and Nichols, using rectangular flumes 1.75 ft wide, for an even distribution of flow, found a deposition of 81.6% occurred in the side channel in 3 hours, 45 min. In other tests at Vicksburg, semicircular cross sections were employed, with the side channel being given an area of

[11] "Diversion of Sediment at Branching Channels," by Gerard H. Matthes, *Transactions*, Am. Geophysical Union, Vol. 14, 1933, p. 506.

two thirds that of the main channel. The discharge through the side channel was less than 50% of the total flow. Also, experimental runs in Germany approximated 1 hour in duration, whereas the runs at Vicksburg were, in some instances, 70 hours long. Mr. Bulle found that the percentage of "geschiebe" moved down the side channel decreased with time. At Vicksburg, the percentage did not decrease. With an increase of time the distribution of flow varied inversely with the distribution of the bed load. After beginning a run, the percentage of "geschiebe" moved into the side channel, and the percentage of flow down the straight channel below the fork, increased for a short time. A period of decrease in both percentages then existed until the vertical roller near the head of the side channel was eliminated. After extinction of the roller, both percentages increased with time. If runs as reported by Mr. Bulle had been longer, he might have noted the increase after the decrease. At Vicksburg it was noted that, once the bed had been built up, deposition and scour were negligible, thus indicating that a condition of equilibrium had been reached. Nature sought the most efficient channel; and, until such a channel was obtained, deposition and scour took place.

Since experiments indicate a greater proportion of "geschiebe" relative to the quantity of water diverted into a bifurcation channel, one naturally looks for the cause. It should be clearly understood that material deposited (and carried through) the side channel is of bed-load nature. Material in suspension has been proved by the aforementioned investigators to divide in a ratio commensurate with the division of flow. Tests, utilizing small celluloid balls filled with water to keep them on the bottom, indicate that practically all the bottom layers of flow turned into the side channel. Current indicators also show most of the water adjacent to the bottom moving into the branching channel.

If one will visualize the vertical velocity distribution formed in most streams, a reasonable argument for the movement of the "bottom layers" into the side channel may be advanced. Immediately next to the bottom a boundary layer retards flow. The momentum of the lower stream filaments is less than that of the upper ones (for equal masses). One may conclude that the greater momentum of the upper filaments of water gives them more of a tendency to continue in a straight line, leaving the supplying of the branch channel largely to the lower stream filaments.

If the lower filaments do move into the bifurcation channel and they possess sufficient velocity to cause the bed load to move, one must conclude that the greater part of the bed load will move into the side channel, for the bed-load movement takes place in the lower filaments of the stream.

Prior Studies of Discharge Capacity at Red River Landing

All the early investigators attempted to deduce the trend in discharge capacity by making comparisons of cross-sectional areas of the rivers over a period of years. Many unpublished papers on this subject are on file in the Mississippi River Commission Library at Vicksburg, but only those papers and documents which have been published will be cited.

In 1914 E. J. Thomas, assistant engineer of the Mississippi River Commission, reported[12] a comparison of the hydrographic surveys of 1895 and 1910, as shown in Table 4.[13]

It will be noted that, except for the low-water stage, the average areas for the reach increased. In the same source Kivas Tully, assistant engineer of the Mississippi River Commission, reported that:

> "From the plotted discharge curves of Red River Landing for 1882 it will be seen that the discharging capacity of the Mississippi River at that point was greater than it has been at any time since. The measured discharge on March 31 of that year was 1,595,000 cu ft per sec at a stage of 48.3 ft. The discharge on May 14, 1897, at a stage of 50.2 ft was only 1,290,000 cu ft per sec. That is, at a stage 1.9 ft higher, the discharge was 305,000 cu ft per sec less."

Mr. Tully also stated that the average area of the reach from ¼ mile above to 1¼ miles below the mouth of the Old River had decreased 18,067 sq ft, or about 8% between 1884 and 1909. Messrs. Thomas and Tully did not agree on the changes in cross-sectional area of the reach.

TABLE 4.—COMPARISON OF HYDROGRAPHIC SURVEYS OF 1895 AND 1910

Stage	Widths (ft)	Areas (sq ft)	Depth (Ft)	
			Mean	Maximum
Low water	+ 803	−22,680	−22.9	−31.0
Medium	+1,487	+31,647	− 5.4	...
Bankfull	+1,463	+51,127	− 5.2	...

The conclusion reached in a subsequent report dated 1919 was that the decrease in channel area was responsible for a decrease in discharge capacity.[14] Continuing the same line of reasoning, in 1931 a report[15] presented the data on the comparison of cross-sectional elements from mile 771.0 to mile 837.1 BC, as shown in Table 5. The changes in average areas from 1895 to 1921 were increases and therefore could not be deemed responsible for any decrease in the discharge capacity of the reach.

TABLE 5.—COMPARISON OF CROSS-SECTIONAL ELEMENTS FROM MILE 771.0 TO MILE 837.1 BELOW CAIRO, ILL.

Stage	Average Area (Square Feet)			Average Width (Feet)			Average Mean Depth (Feet)		
	1895	1921	Change (%)	1895	1921	Change (%)	1895	1921	Change (%)
Bankfull	194,269	195,960	+0.9	3,599	3,503	−2.7	56.0	58.2	+3.9
Medium	151,235	154,259	+2.0	3,256	3,254	0.0	48.5	50.2	+3.5
Standard low	81,095	82,606	+1.9	2,265	2,385	+5.1	38.1	37.5	−1.6

[12] "Separation of Red and Atchafalaya Rivers from Mississippi River," *House Resolution No. 841*, 63d Cong., 2d Session, 1914, p. 20.

[13] *Ibid.*, p. 113.

[14] *House Resolution No. 288*, 66th Cong., 1919.

[15] *House Resolution No. 798*, 71st Cong., 1931, Pt. I.

In 1932, the Corps of Engineers, presented further data[16] on changes of cross-sectional elements for the 2-mile reach below the Old River which indicated a definite channel deterioration (see Table 6).[17] However, it should

TABLE 6.—CHANGES OF CROSS-SECTIONAL ELEMENTS IN THE 2-MILE REACH BELOW OLD RIVER

Year	Width, in Feet			Area, in Square Feet			Mean Depth, in Feet		
	Bank-full	Medium	Low water	Bank-full	Medium	Low water	Bank-full	Medium	Low water
1882–1883	4,138	4,003	3,299	237,860	173,594	75,178	57.7	43.5	23.4
1895	4,277	4,140	3,687	232,814	163,410	59,136	54.4	39.5	16.2
1910	4,559	4,424	3,812	226,857	154,463	43,066	49.8	34.9	11.6
1922	4,631	4,513	3,738	223,235	150,147	40,729	48.2	33.3	11.0
1923	4,612	4,471	3,665	227,312	153,771	44,441	49.3	34.4	12.4
1924	4,673	4,525	3,689	224,771	151,171	42,400	48.1	33.4	11.8

be noted that this occurred between 1882–1883 and 1910. From 1910 to 1924 the average area and mean depth were relatively constant despite the fact that the width was continuing to increase. The changes from 1910 to 1924 may be considered "local, insignificant" changes.

Mr Salisbury[6] used the same data. He noted the change from 1882–1883 to 1924, but failed to consider the fact that most of the change occurred before 1910.

Although a change in cross-sectional elements may be determined in the manner used by early investigators, the writer considers that such a study does not lead to correct conclusions. It is relatively easy to provide for coincident hydrographic surveys over a period of years, but the relation of such a survey line to the direction of flow is subject to change. A survey line may be normal to the flow in one year, and in the following year it may depart as much as 25° from the normal. The later survey would always indicate an increase in area, but the data would be misleading. Also, a change in area at any point does not necessarily imply a change in channel capacity. The latter is determined for the main part by the resistance to flow offered by channel conditions below the reach in question. Quite often many cross sections do not carry their full capacities because of a "bottleneck" below them. Therefore, it is believed that a study of channel cross sections alone is not the correct approach to the determination of the changes in channel capacity of the Mississippi River.

CONCLUSIONS

The student of the Mississippi River today faces a set of conditions entirely different from those encountered by A. A. Humphreys, Hon. M. ASCE, and Henry L. Abbot[18] in at least one respect. Messrs. Humphreys and Abbot had few data available, and most of them were undependable. Their problem called for superior intellectual power to bridge over the gaps, and to reach

[16] "The Improvement of the Lower Mississippi River for Flood Control and Navigation," War Dept., U. S. Govt. Printing Office, Washington, D. C., May 1, 1932.

[17] *Ibid.*, p. 55, Table VI.

[18] "Report on the Physics and Hydraulics of the Mississippi River," by A A. Humphreys and Henry L. Abbot, *Professional Paper No. 13*, Corps of Engrs., U. S. Army, 1876.

rational conclusions. Today the investigator encounters an almost overwhelming amount of information; not in all cases what he would like to have, perhaps, but all of it requiring study so as to be certain that he has not neglected some vital occurrence.

In seeking to determine the effect (on the capacity of the Mississippi River) of the increasing diversion into the Atchafalaya River, the writer has seen fit to discard all measurements prior to 1913. The older data are demonstrably less accurate and cannot be used comparatively in studying the later data. Since dependable data do exist for the years following 1912 (and during that period the Atchafalaya River has increased the most and discharged the most), it seems to him a reasonable step. The older data were obtained with cruder instruments and techniques, and the labor of trying to adjust them to a comparable basis does not seem to be justified.

Prior studies of the effect of the Atchafalaya River diversion which were based on comparison of cross-sectional elements were fruitless, in that the procedure used did not provide the correct approach to the problem. The study made by Mr. Salisbury was the best one made from a technical standpoint, but he reached erroneous conclusions partly because of attaching too much importance to the older data.

The capacity of the Mississippi River at Red River Landing decreased from 1913 to 1930 because of the split channel at Smithland and the bar which formed between Smithland and Red River Landing. The removal of this bar and the corrective dredging in the Smithland main channel restored this capacity to that in 1913 as indicated by the rating curve in Fig. 5.

The increase in capacity between 1939 and 1945 indicated by the measurements taken in 1945 was probably largely a result of the change in equipment and technique by which the data were secured. This conclusion is supported by a study of the Baton Rouge gage.

There has been no noticeable increase in the total annual discharge of the Mississippi River to indicate that the increased diversion was being compensated for on that score.

The laboratory experiments on bifurcated channels afford a clue to the reason that the Mississippi River has not adjusted its bed to a smaller average discharge. These experiments proved that a much larger proportion of the bed load would move down a bifurcating channel than would proceed down the main stream, and that the suspended load would remain in approximately the same concentration in both channels as it was above the bifurcation.

The tendency of an alluvial channel to adjust itself to its average discharge requirements is not questioned. The channel of the Mississippi River, in its lower reaches, is not alluvial in the ordinary sense of the word, as is the section at Greenville, Miss., for instance. The bed and banks, having been laid down in still water, are much more resistant to erosion. The fact that the bed load is largely diverted leaves the river little opportunity to adjust its cross section to reduced discharge requirements.